Priority Topics in Seafloor Engineering Research At the Naval Facilities Engineering Service Center Port Hueneme, California

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LONG-TERM GOALS

Conduct priority research important to the Navy through collaboration between California State University, Los Angeles (CSULA) and the Naval Facilities Engineering Service Center's (NFESC) Ocean Facilities Department, and to further the education of participating CSULA students by active involvement in research and mentoring activities. Expose the CSULA students to research projects important to the mission of the Navy with the intent that they may consider naval careers.

OBJECTIVES

The three-and-a-half year research project (2003-2006) contains three major areas of emphasis:

1. In-Situ Testing of Seafloor Soils (years 1 and 2):
To investigate the penetration resistance of a minicone in sand at shallow penetration depths in order to provide experimental information to correlate measured cone parameters with sand strength properties. Evaluate existing methods to predict relative density and friction angle with the measured cone data. Recommend most appropriate methods or develop new methods to predict sand strength properties based on cone data.

2. Update of the Navy's Handbook for Marine Geotechnical Engineering (year 3):
Revise and update the manual to allow Navy engineers to stay abreast with the latest techniques and analysis methods in marine geotechnical engineering. The manual will be transformed into electronic format, and will incorporate new and innovative engineering solutions and technologies.

3. Educational Program (years 1, 2, 3):
Provide undergraduate and graduate students from typically underrepresented groups the opportunity to actively participate in the research, to allow them to advance their qualifications both educationally and professionally, to enhance their chances of academic success, to provide mentorship, and to prepare the undergraduate students for graduate study. Expose them to projects that are important to the mission of the Navy, and encourage them to consider careers that support naval research and development efforts.

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14. ABSTRACT
Conduct priority research important to the Navy through collaboration between California State University, Los Angeles (CSULA) and the Naval Facilities Engineering Service Center?s (NFESC) Ocean Facilities Department, and to further the education of participating CSULA students by active involvement in research and mentoring activities. Expose the CSULA students to research projects important to the mission of the Navy with the intent that they may consider naval careers.

15. SUBJECT TERMS

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APPROACH

In-Situ Testing of Seafloor Soils (years 1 and 2):

In-situ testing techniques have proven to be successful at improving the quality, reliability, and speed of marine geotechnical investigations. The most commonly used in-situ method for offshore investigations is the cone penetration test. Our collaborators at NFESC, Dr. Kimo Zaiger and Mr. David Thompson, have recently acquired a custom-designed and built minicone penetration system that will be capable of obtaining accurate and reliable geotechnical information within about the upper 2 meters of the seafloor. The mini-cone has a tip base area of 2 cm^2, which is smaller than the conventional 10 or 15 cm^2 cone. The primary advantage of this configuration is the smaller downward thrust needed to advance the penetrometer into the seafloor and ability to identify very thin lenses. However, calibration information is needed to correlate the measured mini-cone parameters to soil strength properties. This will be accomplished through the following tasks.

Perform Mini-Cone Soundings in Controlled Sand Test Beds: Mini-cone soundings to shallow depths are being conducted in carefully prepared sand test beds where soil properties and boundary conditions are controlled.

Conduct Laboratory Tests to Determine Test-Bed Soil Parameters: Parallel laboratory tests are being conducted on the sand to similar densities and under similar boundary conditions to the test beds. The test bed soils are being characterized by conducting appropriate laboratory index and strength tests such as grain size distribution, petrographic analysis, relative density, and drained triaxial compression testing.

Calibrate Mini-CPT Test Results with Laboratory Test Measurements: Conventional cone sizes have well-established correlations for identifying soil types and strength parameters. However, these correlations have not been extensively verified for minicone results and have been generally unreliable for soil depths less than about 2 meters. In this task, existing correlations to interpret conventional cone test results for sands are being used to compare the minicone tests results with the results of the laboratory tests. Based on the results of this evaluation, refinements to the algorithms will be made to best fit the laboratory and field data.

Update of the Navy's Handbook for Marine Geotechnical Engineering (year 3):

In 1985, the Naval Civil Engineering Laboratory (NCEL) in Port Hueneme, now called the NFESC, published a manual entitled, *"Handbook for Marine Geotechnical Engineering."* The purpose of the handbook was to provide those navy engineers with a limited background in geotechnical engineering, a single source of information addressing the more important aspects of seafloor behavior for application to Navy deep ocean engineering problems. The handbook quickly became the definitive source for navy and private sector engineers worldwide on how to solve complex and specialized marine geotechnology problems.

Over the past 20 years however significant advances in marine geotechnical engineering has evolved. In this task a newly revised and updated manual will be created that will allow Navy engineers to stay abreast with the latest techniques and analysis methods in marine geotechnical engineering. The manual will be revised in the sense that it will be transformed into an electronic format, and it will be updated in the sense that new and/or innovative engineering solutions and technologies developed

since 1985 will be incorporated. Working closely with Mr. David Thompson of the NFESC we will first survey end-users of the manual to generate feedback about strengths and weaknesses of the current edition. Results of this step will provide direction as to what should or should not be added or deleted from the updated version and a table of contents will be prepared. Next, a professional database search of the main topic keywords in the technical literature will be conducted. Once the information is collected, categorized, and prioritized, discussions with NFESC engineers will be held to decide which information is important and should be included in the update.

Finally, new text will be written, edited, and incorporated into the manual. New figures will be created electronically using graphics software and inserted into the text. The figures of the original manual will have to be scanned or recreated in electronic form using graphics. The manual will be proofed and re-edited. The finished product will reproduced by NFESC and made available in electronic form and distributed.

Educational Program (years 1, 2, 3):

Three undergraduate students will be chosen and designated "Office of Naval Research Scholars." The undergraduate students will be provided a quarterly stipend as well as a travel allowance to participate in research activities at NFESC headquarters in Port Hueneme and for attending professional conferences. The students will also be required to participate in a summer-long internship at NFESC headquarters conducting related research between their junior and senior years. One graduate student will be selected to pursue a M.S. degree and write a thesis based on the minicone penetration testing.

The three undergraduate ONR scholars and the graduate student will be involved in each of the major tasks throughout the duration of the project. They will actively participate in planning activities, project scheduling, gathering and disseminating available literature, and execution of the specific research tasks and subtasks. The students will be mentored throughout the research period.

They will be encouraged to present their findings to the CSULA community through the yearly campus symposium and through other venues. In this way, the students will have an opportunity to showcase their skills in front of civil engineering leaders from the public and private sector. Additionally, they will be encouraged to submit papers and attend at least one professional ocean related conference per year. By attending conferences, students will have the opportunity to learn from and interact with other researchers with similar interests, make contacts in the profession, and network with possible future employers.

Since many CSULA students are the first in their family to attend college, they will also be encouraged to promote themselves as role models within their community. They will be encouraged to participate in outreach events to local area high schools and community colleges to educate and encourage others about the Navy's R&D efforts and the benefits of the engineering profession.

WORK COMPLETED

In-Situ Testing of Seafloor Soils (years 1 and 2):

In year 2 of this research task we have completed an additional 55 penetration soundings (38 minicones and 17 standard cones) in four sand test beds prepared at a range of relative densities. This

brings our two year total to 106 penetration soundings (71 minicones and 35 standard cones), which constitutes a large an important data set to be analyzed.

We have also completed 13 drained triaxial compression tests and 12 direct shear tests to determine the friction angle of the test sand. Index tests were also performed to determine the grain size distribution, specific gravity, and maximum and minimum dry densities of the sand. Using the results of the penetration soundings and the laboratory tests we have evaluated six correlations to predict friction angle of sand from cone tip resistance.

Update of the Navy's Handbook for Marine Geotechnical Engineering (year 3):

We are at the beginning stages of this task but have made important headway. Through several meetings with the engineers at the NFESC we have outlined a plan for completion of the manual. Several end-users have already been consulted to help identify the portions of the manual to be updated. The three ONR scholars, during their summer internship at the NFESC, have completed a major milestone by re-creating the manual's existing figures in electronic form using Auto-CAD and Microsoft Excel. The next tasks will be to further refine the table of contents and conduct a literature review of topics that will be updated and compile the information into an electronic format for editing and eventually for distribution.

RESULTS

In-Situ Testing of Seafloor Soils (years 1 and 2):

Results from the 55 penetration soundings conducted this year as well as the previous soundings have been interpreted and analyzed. A summary of the mean minicone tip resistance profiles in loose, medium dense, and dense sand are shown on Figure 1. The figure shows that the cone tip resistance increases rapidly during initial penetration until a critical depth is reached, at which point the tip resistance increases at a slower rate or reaches a constant value with further penetration. This tip resistance behavior is similar to studies using standard cones in homogenous sand provided in the literature (e.g. De Beer, 1974; Mitchell and Lunne, 1978; Puech and Foray, 2002). Increasing the density of the sand increased the value of the maximum tip resistance and deeper penetrations were required to reach the critical depth. The measured values of maximum tip resistance and critical depth compared well with other published data on sands at shallow penetration.

Five correlations were used to predict the friction angles from the measured minicone tip resistance profiles. These values were then compared with friction angles obtained from triaxial compression tests as shown on Figure 2 for the loose and dense sand test beds. Of the methods evaluated, the Robertson & Campanella and Durgunoglu & Mitchell methods predicted the measured friction angle the closest, especially for the loose sand. They slightly overpredicted the friction angle for the dense sand. The Robertson & Campanella method is empirically based and simple to use. The Durgunoglu & Mitchell Method is more complicated to implement but was developed specifically for shallow penetration and can account for cone diameter.

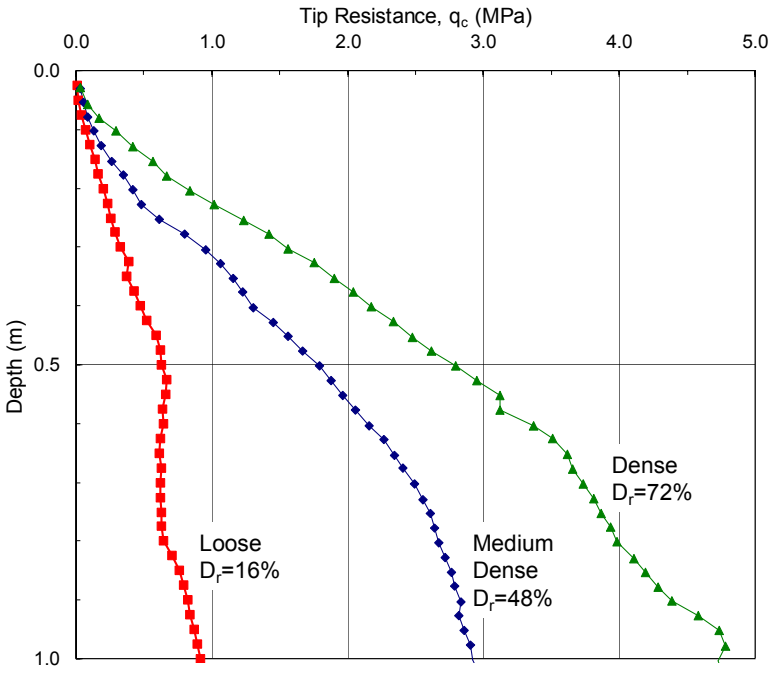

Figure 1. Minicone tip resistance profile in loose, medium dense, and dense sand at shallow penetration illustrating rapid increase of tip resistance followed by a decrease with depth.

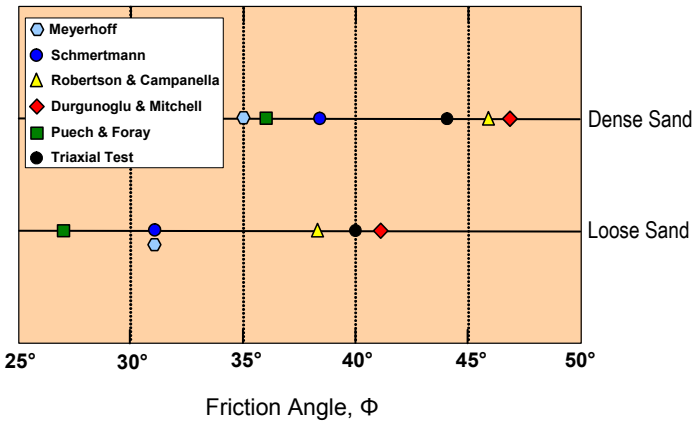

Figure 2. Comparison of friction angles determined from various methods at shallow penetration for mincone with friction angles measured in triaxial tests.

Update of the Navy's Handbook for Marine Geotechnical Engineering (year 3):

The update of the manual is just getting underway but significant progress has already been made. Converting all of the existing figures in the manual into electronic format was a major accomplishment. The NFESC has also received funding that will allow a commitment of staff hours to help in completion of the manual update.

Educational Program (years 1, 2, 3):

The three undergraduate ONR Scholars (Valerie Nevarez, Michael Soto, and Jonathan Janer) have been in the program now for two years. They entered the program as freshmen and are now juniors pursuing their B.S. degree in Civil Engineering. They spent the past summer interning at the NFESC in Port Hueneme working closely with the Ocean Engineering group on a variety of seafloor engineering topics. Their tasks included analysis and field testing of skirted foundations, cone penetration calibration and testing, GIS applications, and tasks related to the update of the Marine Geotechnical Handbook. They were also responsible for conducting the triaxial and direct shear tests on the test sand at the CSULA soils laboratory.

Aside from their technical research activities, they have also been involved in a number of professional development and outreach events. They have discussed their research project to groups of students at Pasadena Community College and at a convocation at UCLA. They have worked with and mentored an Alhambra High School senior who used the minicone testing research as part of his school's science project. They also attended a workshop on cone penetration testing where they learned about the state-of-the-art in in-situ testing and networked with local engineers and scientists.

They prepared and presented a technical poster on their research at the Southern California Conference on Undergraduate Research at Whittier College, and at the CSULA 13th Annual Symposium on Research, Scholarship, and Creative Activity. At the CSULA event, they received 1st prize for their poster and presentation. The students also prepared a paper (Janer et. al., 2005) and a poster for presentation at the 2005 MTS/IEEE Oceans Conference in Washington D.C. as shown in the photograph on Figure 3.

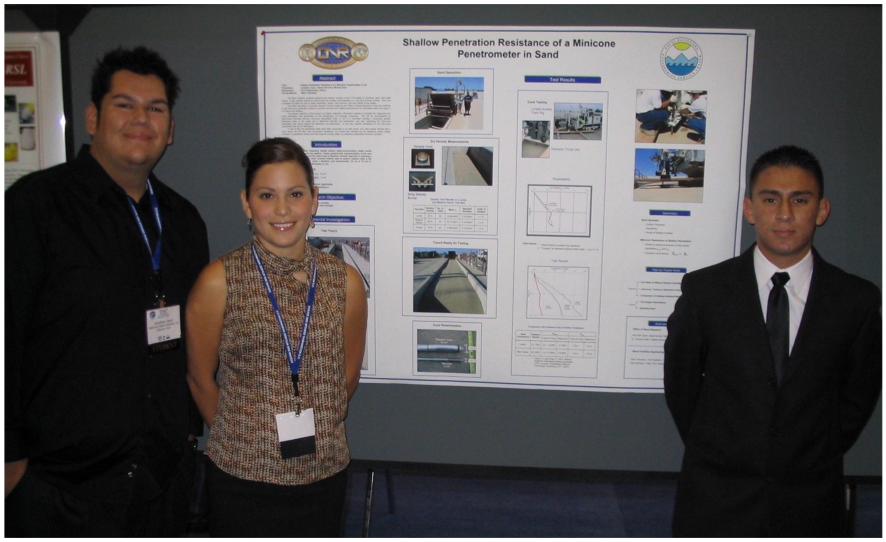

Figure 3. ONR Scholars Jonathan Janer, Valerie Nevarez, and Michael Soto presenting their research results at the 2005 MTS/IEEE Oceans Conference poster session in Washington D.C.

The graduate student (Eric Yee) was hired about one-and-a-half years ago and is completing an M.S. degree in Civil Engineering and a thesis on the minicone testing research. He too has been active in the research and outreach activities. He also has been an important mentor for the three undergraduate ONR Scholars. He published and presented a paper (Yee et. al. 2005) on the Naval Seafloor Engineering Research Program at CSULA at the 2005 MTS/IEEE Oceans Conference in Washington D.C.

IMPACT/APPLICATIONS

The results thus far have added to the understanding of the minicone penetration response of sands at shallow depth. An important data set has been generated that will allow continued analysis for some time to come. The results of this research have validated correlations used to predict the friction angle of sand from cone penetration resistance. This information can readily be used by the Navy for identification of geotechnical properties of near surface seafloor soils during installation of military seafloor cable systems in sands.

The educational program has provided the participating students an opportunity to further their education and conduct research important to the Navy. They unanimously agree that it has been a great learning experience and have developed many soft and hard skills otherwise not available to students. Their participation has allowed them a more informed career choice and exposed them to academic research and professional work important to the Navy.

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PUBLICATIONS

Janer, J., Nevarez, V., and Soto, M., 2005, "Minicone Penetration Testing of Seafloor Soils," *Proceedings of Oceans 2005 MTS/IEEE*, September 18-23, Washington D.C. [published].

Tufenkjian, M.R., and Thompson, D.J., 2005, "Shallow Penetration Resistance of a Minicone in Sand," *Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering*, Osaka, Japan, September. [published].

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Yee, E., Tufenkjian, M.R., Soto, M., Janer, J., and Nevarez, V., 2005, "The Naval Seafloor Engineering Research Program at California State University, Los Angeles," *Proceedings of Oceans 2005 MTS/IEEE*, September 18-23, Washington D.C. [published].

HONORS/AWARDS/PRIZES

Certificate for *Outstanding Presentation in the Poster Session*, 13th Annual CSULA Symposium of Research, Scholarship, and Creative Activity, February 25, 2005.